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MICROBIOLOGY OF GRANULAR ACTIVATED CARBON HOME TREATMENT DEVICES

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16. ABSTRACT

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Microbiology of Granular Activated Carbon Home Treatment Devices

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ABSTRACT

Consumer usage of point-of-use granular activated carbon filtration devices is increasing rapidly, yet there is little information available to the consumer concerning the efficacy of these devices. In particular, the consumer is very likely to be unaware of the fact that these devices frequently generate large numbers of bacteria that are shed in the product water. Studies of point-of-use treatment devices indicate that the bacteriological quality of product water varies both within units of the same design and among units of different design. Important factors in development of bacterial populations include the length of time that a filter cartridge is in service, water temperature, flow rate, construction materials, and the quality of the influent water. Some units contain silver as a bacteriostatic agent; its effectiveness is questionable, however, because heterotrophic bacteria concentrations associated with such units are often as high as those found for non-silver containing units. Although long-term sampling of test

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units indicates that a wide variety of bacteria can be isolated, including some opportunistic and frank pathogens, little or no information is available on adverse health effects to consumers from ingestion of water from point-of-use treatment devices.

INTRODUCTION

Installation and use by the public of in-the-home, point-of-use (POU) water treatment devices has increased substantially in the past several years, and it is estimated that more than a million families already use these devices. The trend has paralleled increased consumer awareness of potential health risks identified with consumption of water in some community water systems.

According to the Water Quality Association, the POU water treatment industry includes more than 200 manufacturers, nearly 5,000 retailers, distributors and wholesalers and nearly $1 billion in annual sales.

Point-of-Use treatment units fall into two categories, water treatment units and water purifier units. Interim Requirements for Registration of Bacteriostatic Water Treatment Units for Home Use were set forth in the Federal Register, 14(152):32778-32782, Thursday August 5, 1976. Regulation of POU water purifier units is covered under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) as amended (86 Stat. 973, 7 U.S.C. 136 et seq.) and registration of such devices is handled by the Office of Pesticides Programs, U.S. Environmental Protection Agency.

Water Treatment Units. Any unit intended for physical and/or chemical treatment of microbiologically potable water to remove undesirable tastes, odors, chemicals, or other aesthetically objectionable properties is identified as a potable water treatment device. Water treatment units that

contain a bacteriostatic agent are under the purview of FIFRA. Units containing a bacteriostatic agent to control bacteria can be represented by the manufacturer as "water treatment units", "water clarifiers", "water filters", or "water deodorizers", or similar names which do not imply water purification.

Water Purifiers. Any unit intended for the treatment of raw water to eliminate the potential health hazard posed by microorganisms is identified as a water purifier unit. Included in this category are: 1) units that rely on physical removal such as filtration (these are termed pesticidal devices and are subject to regulation but not registration); 2) units that rely on chemical treatment (pesticides); and 3) units that utilize a combination of physical removal plus chemical treatment.

Regulation of these devices also covers labeling and labeling claims. The labeling must contain: 1) adequate directions for use, and 2) adequate warning or caution statements. Also, the labeling must not contain any statement, design, or graphic representation which is false or misleading.

Public interest in home POU water treatment devices is usually based on concern over removing carcinogenic chemicals or improving the aesthetic quality of the drinking water, including removal of tastes and odors, color and particulates. Many of these home treatment devices have a third faucet. Third faucet units may be any type of POU device that can be plumbed to deliver the treated water to a faucet separate from the normal hot and cold water faucets, or separate from a mixer faucet. The majority of third faucet POU treatment devices contain granular activated carbon (GAC) for filtering the water, but other treatments such as reverse osmosis, fine filtration, chemical disinfection, ion exchange or ultraviolet irradiation may also be

used either alone or in combination with some other treatment.

A major concern with POU potable water treatment devices addresses the microbiological, particularly the bacteriological, characteristics of these units. We have been conducting a study of some of these devices for several years now, and in the current and final phase we are looking at several third faucet type units. This paper will discuss some general findings concerning the bacteriology of these units. We have looked only at potable water treatment units, as previously defined, and at some bacteriostatic units during this study. The intent is not, and never has been, to examine these units for the purposes of rating, recommending or indicting any of them. We are concerned with the microbiological quality of the product water as compared to quality of the influent water. Furthermore, reasonable worst case conditions were established in which the filter cartridges were installed and left in use for a period of time in excess of that recommended by the manufacturer. This was done to simulate the situation in which a consumer, either inadvertantly or through ignorance or neglect, fails to change the filter cartridge(s) as recommended by the manufacturer. Furthermore, the supply water to the test units was dechlorinated to simulate conditions in which bacteria that survived the utility treatment and disinfection process become the seed organisms that colonized the test units.

MATERIALS AND METHODS

The testing setup, shown schematically in Figure 1, provided a simulated daily use cycle consisting of seven flow periods that ranged from 28 seconds to 3.5 min. and approximately a 12 h. non-flow period overnight, all controlled by timers and solenoid operated valves. The total time of flow during each 24 h. was about 12.9 min. at approximately 1.5 gal./min., or about 19.3 gal. (73.1 L)/day.

Water samples were collected morning and afternoon twice per week using Standard Methods, 16th Ed. procedures (1), and analyzed for heterotrophic plate count (HPC) bacteria using R2A spread plates incubated at 28°C for 7 days (5). Differential counts of pigmented bacterial colonies on the plates were made in addition to the total counts. When units were challenged using a pure culture of a selected organism, an appropriate selective medium for the test organism was used as follows: for K. pneumoniae, m-Endo medium (1), for Aeromonas hydrophila, m-PA medium (7), and for Yersinia enterocolitica, CIN agar (8). Challenge organisms were dosed into the dechlorinated supply water through a rubber septum using a syringe and needle. Water sample volumes of up to 500 ml were membrane filtered for recovery of challenge organisms and appropriate incubation conditions were utilized for each organism.

RESULTS

The HPC of the product waters from the POU devices showed considerable variation in several ways. First, for each unit, there was variation depending on the time of sample collection (AM vs. PM). For example, Figures 2, 3, and 4 show the mean HPC in colony forming units per milliliter (CFU/ml) for Units 1 and 4 and the dechlorinated tap water (TAP), respectively, for the period of October - December 1984. Differences between the AM versus PM HPC as shown in Figure 2 have been found for all the POU devices tested so far. The magnitude of the HPC difference between the AM and PM sample varied with each POU unit. The increased counts in the AM samples were due to the overnight quiescent period during which time the bacteria were able to multiply. Figure 2 also shows the variation in the mean HPC from October to December, 1984. The declining mean HPC from October to December reflects the effect of decreasing water temperature. As the temperature decreased,

bacterial metabolism also decreased and the free chlorine residual remained higher since chemical reactions also slow down at lower temperatures. The total number of pigmented bacteria tended to remain fairly constant although there were changes in the proportions of various pigmented subgroups.

Figure 3 is similar to Figure 2 but shows the mean HPC for Unit #4. The trend for this unit was toward an increasing HPC, but the numbers of pigmented bacteria were very low. The HPC of product water from Unit 4 was the highest recorded for any of the units tested. This probably reflects the design of the unit, the way the cartridge is loaded with GAC, and perhaps the materials used in the construction of the cartridge.

Figure 4 shows the mean HPC and pigmented counts of the control water (TAP) which was dechlorinated Cincinnati tap water. Dechlorination was achieved by passing the water through a Sears* taste and odor cartridge. The bacterial flora of the dechlorinating filter provided the bacterial seed to the other test units. The mean HPC of the TAP water was always lower than that of the test units.

Figure 5 shows mean AM and PM HPC results for the seven test units and the TAP water for the period October through December, 1984, and illustrates the variability observed in the bacteriological quality of the product water from each of the units. Units 1, 5 and 6 contained silver as a bacteriostatic agent. The effectiveness of silver in limiting or controlling the bacterial population is suspect, however, since units that contained silver often had HPC results as high or higher than units without silver. Qualitatively, the appearance of the HPC plates was different from test unit to test unit and particularly so for those that contained silver.

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*Sears Roebuck and Co., Chicago, Ill.

Figure 6 shows the mean percentage of pigmented bacteria, expressed as percentage of the total HPC, for the AM and PM samples for each of the 7 test units and the TAP for October, November and December, 1984. The designation TOT is the total percentage of pigmented bacteria and is the sum of the percentages of the yellow, pink, orange and "other" pigmented bacteria. The variation among the test units in the percentage of pigmented bacteria is readily apparent. All the test units modified the percentage of pigmented bacteria to a considerable extent compared to the TAP results in which nearly 50% of both the AM and PM total HPC was composed of pigmented bacteria. Unit 4 had the highest HPC of all the test units, but yielded the lowest occurrence of pigmented bacteria. Apparently, this unit selected for a non-pigmented bacterial population that simply overwhelmed the pigmented bacteria. The TAP water consistently yielded a rather high proportion of pigmented bacteria.

Figures 7 and 8 compare representative afternoon (PM) HPC results for old filters (18 months on line) for units 1, 2, 5 and the TAP versus new filters for the same units. Figure 7 shows the HPC of old filters for a 6 week period in July-August, 1985 and the curves indicate that old filters tend to become relatively stabilized with respect to the HPC numbers. On the other hand, the HPC of new filters (Figure 8) changed rapidly within the first week after being placed in service and then became relatively stable. Unit 2 for example showed a 3-log increase in HPC in a period of one week, and the HPC of the water from that unit remained high for the remaining five weeks of the comparison period. Thus, microbial colonization and growth in POU GAC cartridges occurs very quickly and very high densities of bacteria may be achieved.

All the current test units have been challenged with pure culture

inocula of three different opportunistic or frank pathogens (data not shown). The challenge bacteria used were Klebsiella pneumoniae, Yersinia enterocolitica and Aeromonas hydrophila, and none could be shown to colonize the units. Organisms yet to be tested are Campylobacter and Legionella pneumophila. In a previous study, the only challenge organism that was shown to colonize was Pseudomonas aeruginosa, and once introduced, the organism remained until the test set-up was thoroughly disinfected with hypochlorite solution (4).

DISCUSSION

Our results to date confirm and support results reported by other investigators. High bacterial counts in water collected early in the daily use cycle or after varying lengths of quiescence have been reported (3, 4, 6, 10, 11). The bacterial concentration in the product water was shown to decrease, sometimes dramatically, after the filter was flushed thoroughly before taking the sample. The AM to PM variation in bacterial concentration shown for all units tested in this study was due to the flushing that occurred during the flow periods prior to the afternoon sample collections. Thus flushing the unit by allowing the water to flow at full volume for 30 seconds, or at least until the full bed volume of the filter unit has been displaced, will reduce the bacterial concentration in the product water. It is recommended that this be done before drinking the water from the POU device.

Variations in HPC among different filter units and among units of the same type has also been shown in other studies (3, 4, 9, 10). The month to month variation observed for the test units during this study was also observed in our previous study using different filter devices (4). The variations in the HPC appeared to be related to water temperature and to increased or decreased concentration of residual disinfectant as affected by the water temperature.

The HPC level for each filter unit that had been in use for several weeks became stabilized, but showed some variation. New filters, on the other hand, showed low initial HPC levels that increased rapidly within the first two or three weeks of use and then also become relatively stable.

Silver is incorporated into the GAC filter cartridge by some manufacturers as a bacteriostatic agent. Silver has been shown to be effective against some bacteria such as coliform organisms, but has little effect on the HPC in general (10). In this study test units 1, 5, and 6 contained silver (Figure 5). Units 1 and 6 had considerably higher HPC levels than the TAP, but unit 5 had HPC levels approximately equal to the TAP. Qualitatively, HPC plates from those units that contained silver appeared to have some different colony types than the HPC culture plates from the test units without silver. The silver appeared to exert a selective influence such that silver tolerant bacterial populations often developed to densities equal to or higher than the units without silver. Thus, silver was not effective as a bacteriostatic agent in all the test units that contained it and silver is definitely not effective against all bacteria.

The occurrence of pigmented bacteria in the treated water was of interest because significant populations of pigmented bacteria are often found in treated distribution water. The organisms, in general, appear to be a significant part of the normal bacterial flora of clean water. They often occur in higher numbers in waters low in nutrients; i.e. oligotrophic waters. In the case of point-of-use treatment devices, the pigmented organisms were considered as potentially useful markers that might aid in interpreting the changes in the microbiological quality of the product waters. Although the TAP water always showed a rather high percentage of the pigmented bacteria,

each of the point-of-use devices caused some modification in the proportion of pigmented bacteria.

Generally, the percentage of pigmented bacteria in water from the filter devices was considerably less than that found in the TAP water, but actual numbers of pigmented bacteria and the total HPC in water samples from the filter units were usually larger than in the TAP waters. The afternoon samples usually showed a decrease in the percentage of pigmented bacteria reflecting the wash out of these organisms, but the decrease was usually a matter of only a few percent. The decreased proportion of pigmented bacteria in the product water from all the devices is probably due to several factors including competition for nutrients, faster growth rates of non-pigmented bacteria versus the pigmented forms, inhibition, increased nutrient concentrations at the carbon surface, and perhaps design and construction materials of the various filter devices. In general, the pigmented forms are slower growing bacteria and appear unable to compete as well with the non-pigmented bacteria when nutrient concentrations are increased.

Although the HPC of the filter units often reached high levels, the bacteria that were found in the product water do not appear to be of significant health concern. They may, however, be a significant factor in preventing pathogenic strains of bacteria from colonizing and persisting in GAC filter cartridges.

Challenges of test filter units with specific bacterial pathogens (Klebsiella pneumoniae, Aeromonas hydrophila and Yersinia enterocolitica) in this study did not result in colonization of the test filters. Camper et al. (2), using pure cultures of Y. enterocolitica, Salmonella typhimurium and an enterotoxigenic Escherichia coli, showed that all three of these

organisms in sterile river water readily colonized sterile GAC and maintained high populations for at least several days. However, when the GAC had an established biofilm of river water bacteria, the pathogens attached at a lower rate and decreased in concentration rather rapidly. In both this study and the study by Camper, et al., the concentration of pathogens introduced into the GAC was higher than would be expected from a contamination event in a potable water system. In our study, the pathogen concentration used was about 200-500 cells/unit and was considered a more possible contamination dosage. On the basis of data presently available, it appears that the pathogenic bacteria that have been tested will generally not colonize and/or persist long in GAC filter devices that already have a biofilm population of non-pathogen heterotrophic bacteria.

RECOMMENDATIONS

For individuals who use home POU treatment devices, the general implications of this and other studies suggest the following practical guidance to reduce the bacterial concentration in the POU treatment device product water:

1. Use the POU device only on a microbiologically safe water unless the manufacturer specifically recommends it for other applications as well.
2. Prior to using the product water from a POU device, allow the water to run to waste for about 30 seconds, or at least until sufficient water has passed through the unit to have replaced the water volume of the cartridge. In particular, this procedure should be followed after an overnight stagnation period in order to reduce the bacterial content of the water and avoid taste and odor problems.

3. When the POU unit has not been used for several days due to a vacation, etc. flush the unit for a longer period of time at full flow, preferably up to 2 or 3 minutes.

4. Change the filter cartridge at least as frequently as recommended by the manufacturer, or preferably more often.

5. Adhere to the manufacturer's maintenance recommendations and to any specific instructions relative to changing the filter cartridge(s).

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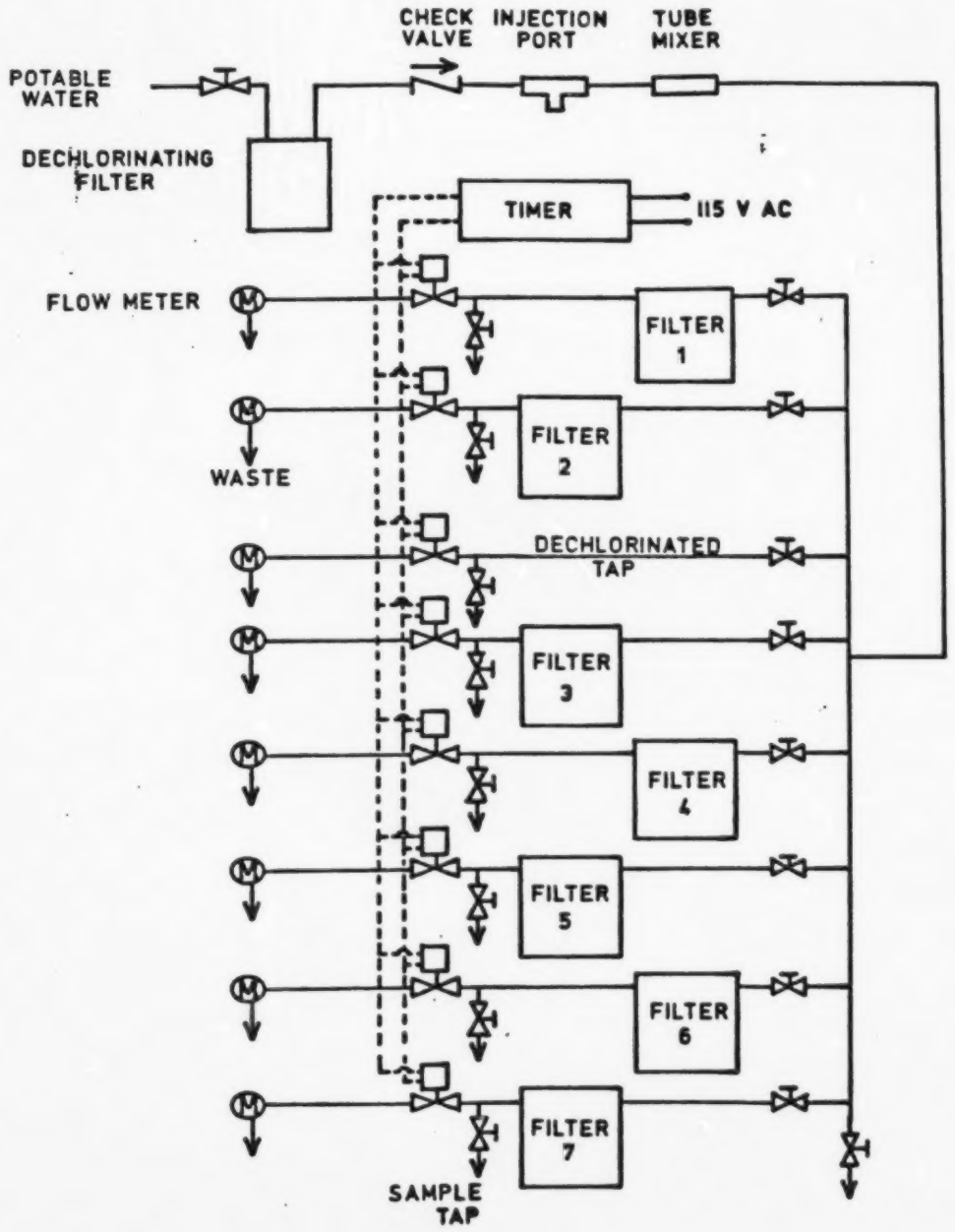


FIGURE 1. **Schematic of Point-of-Use Test Set-up**

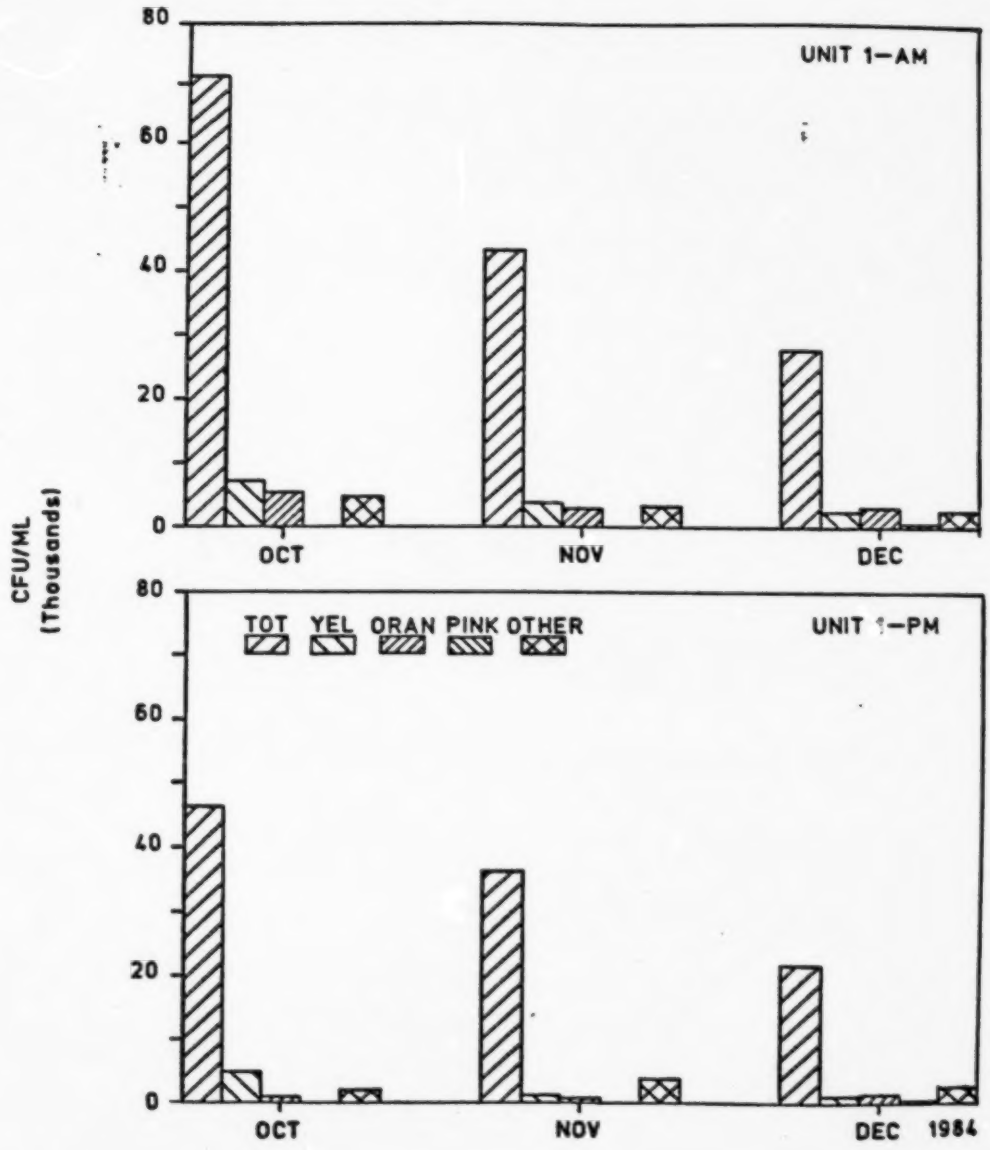


FIGURE 2. MEAN R2A HPC AND PIGMENTED BACTERIA

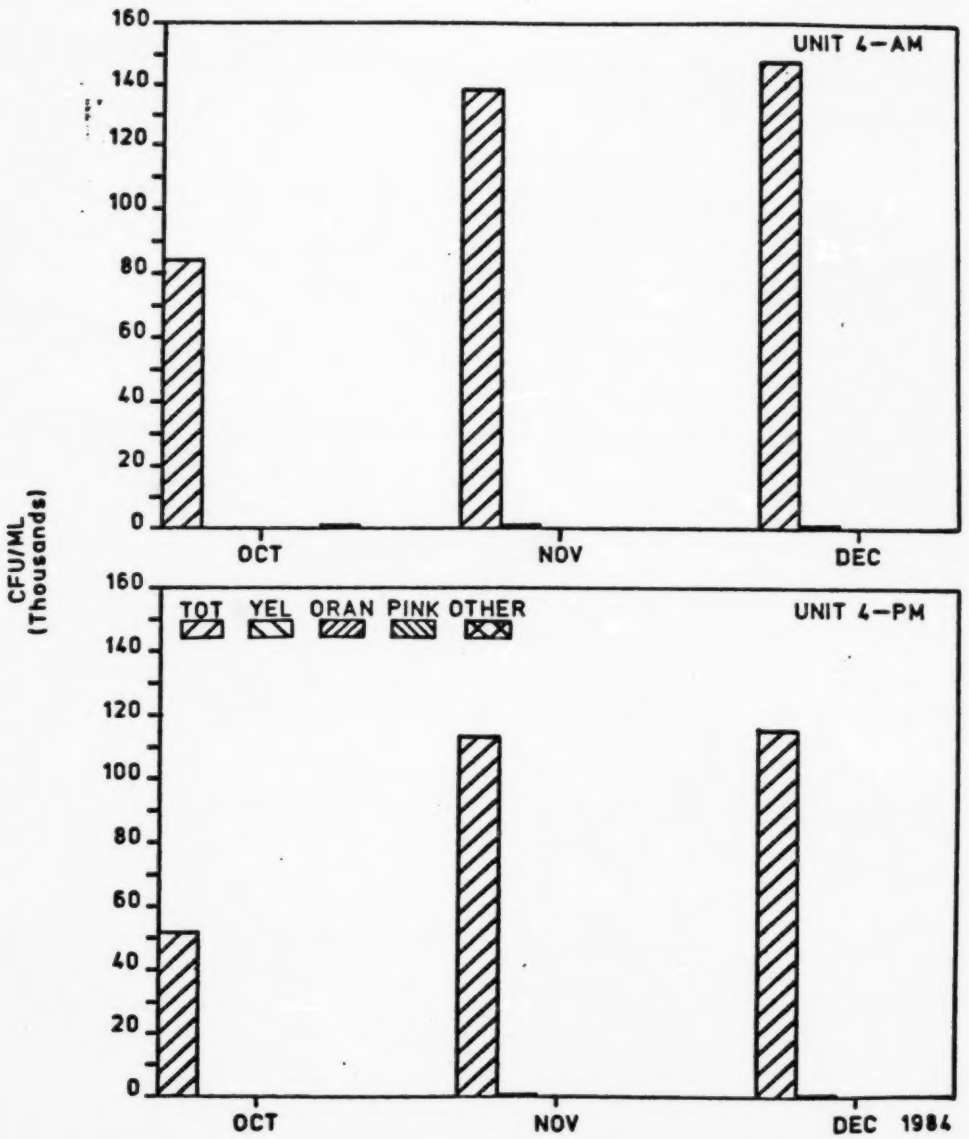


FIGURE 3. MEAN R2A HPC AND PIGMENTED BACTERIA

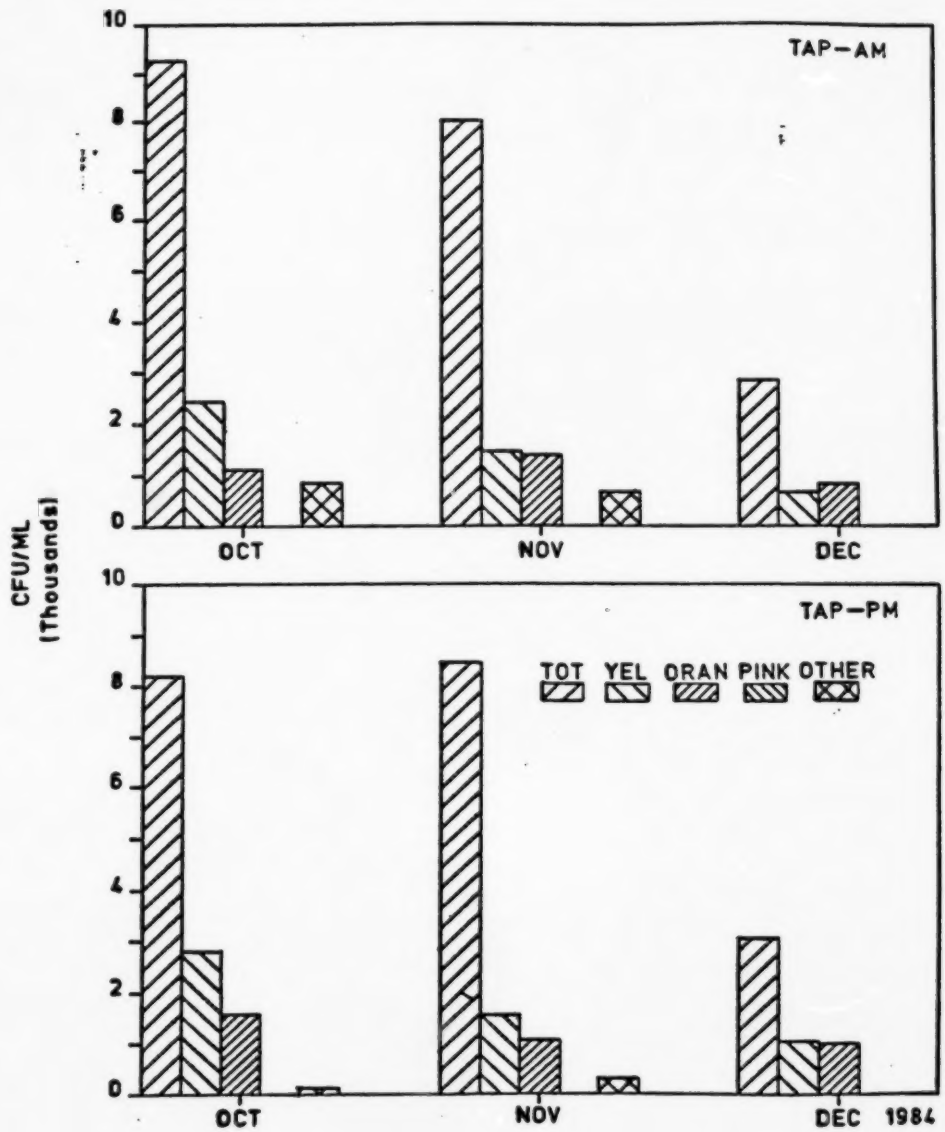


FIGURE 4. MEAN R2A HPC AND PIGMENTED BACTERIA

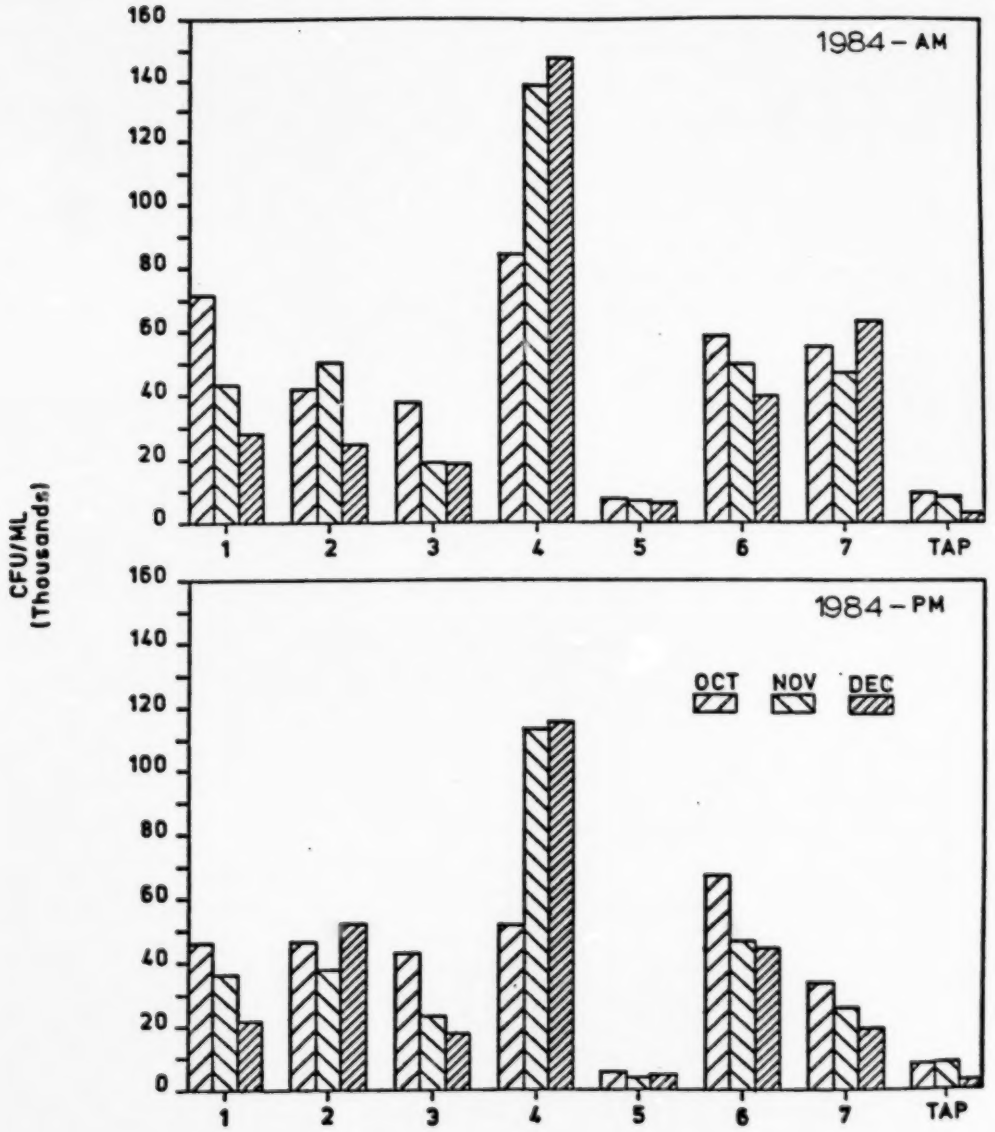


FIGURE 5. QUARTERLY MEAN R2A HPC BACTERIA

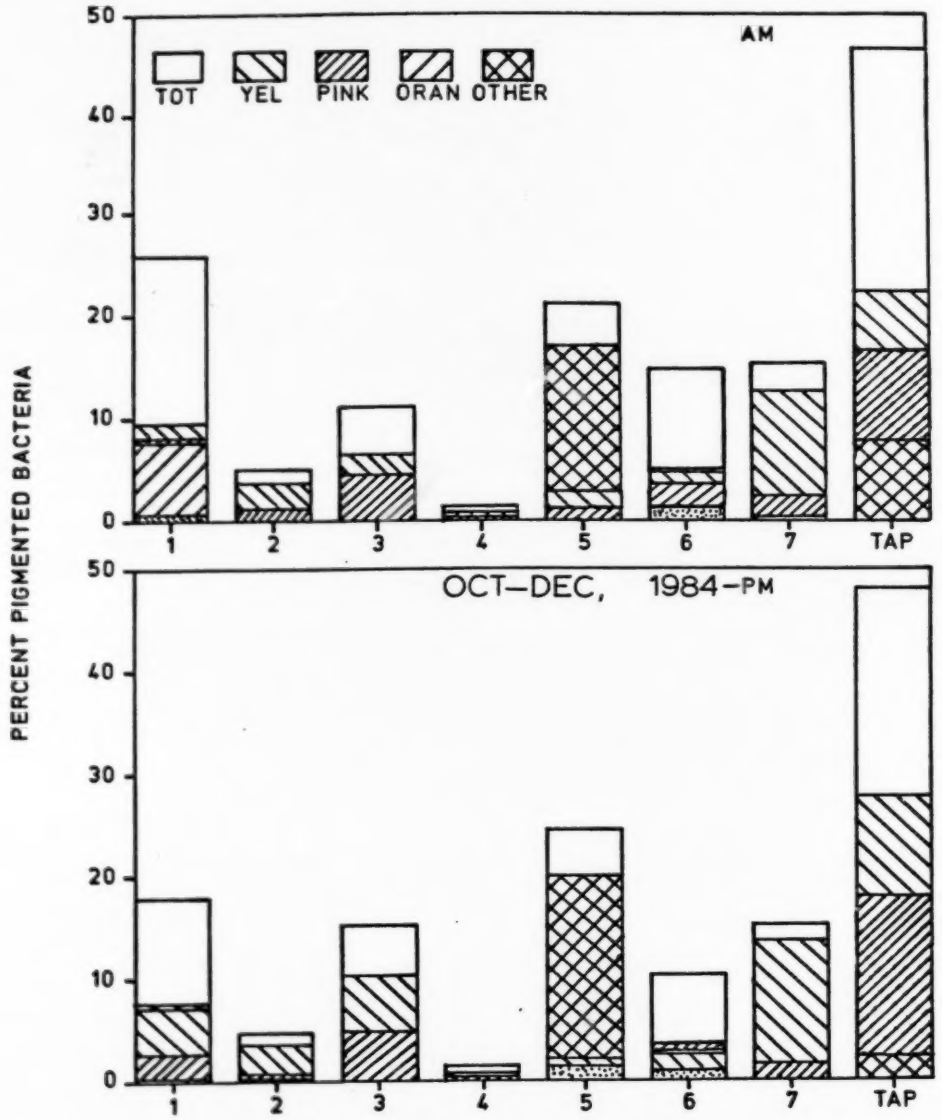


FIGURE 6. QUARTERLY MEAN PERCENTAGE PIGMENTED BACTERIA

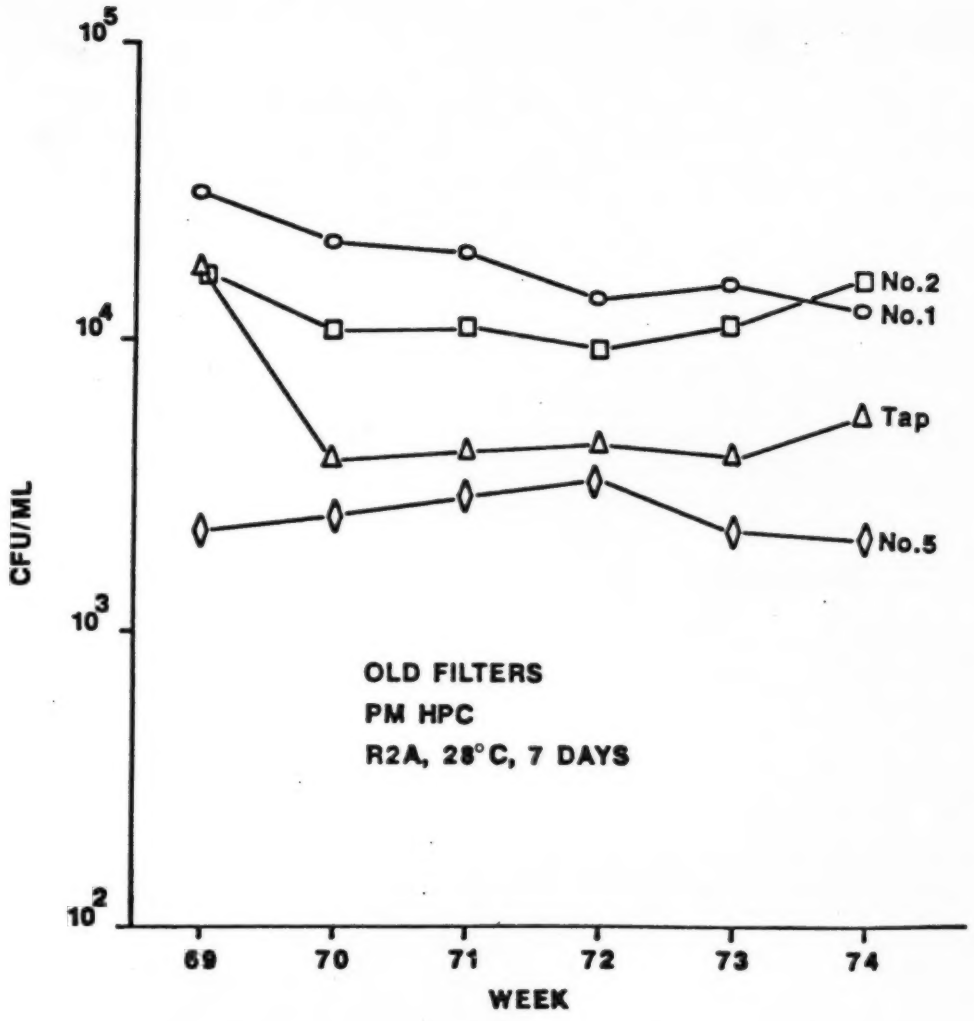
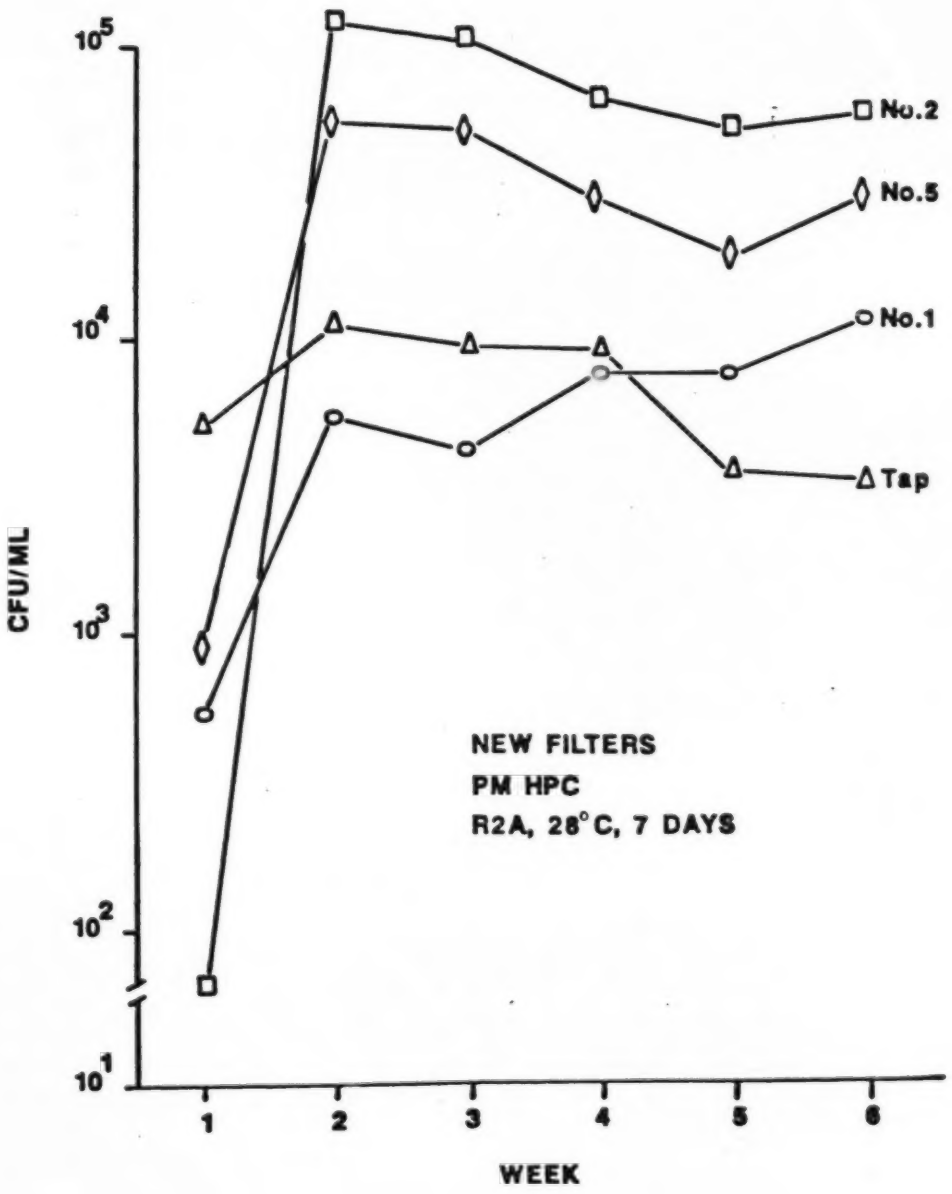

10^5
10^4
10^3
10^2
CFU/ML
No.2
No.1
Tap
No.5
OLD FILTERS
PM HPC
R2A, 28°C, 7 DAYS
69
70
71
72
73
74
WEEK

FIGURE 7.


10^5
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NEW FILTERS
PM HPC
R2A, 28°C, 7 DAYS
1
2
3
4
5
6
WEEK

FIGURE 8.